Board 35: A Creative Approach to the Undergraduate Research Experience

Dr. Ferris Pfeiffer, University of Missouri
Dr. Johannes Strobel, University of Missouri

Dr. Johannes Strobel is Professor, Information Science & Learning Technologies at the University of Missouri where he leads a maker space initiative and conducts research in STEM education, particularly engineering. His research and teaching focuses on engineering as an innovation in pre-college education; learning through hands-on activities; and empathy and care in engineering. He published more than 140 papers in proceedings and journals (many with graduate and undergraduate students) and directed large scale projects in engineering education research. He is the founding editor for the Journal of Pre-College Engineering Education, co-editor of the book "Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices" and "Technology Education Today: International Perspectives" and co-lead author of Hands-on Standards STEM in Action, an award winning internationally available set of learning modules for grades preK - 5th grade published by ETA hand2mind and LearningResourcesUK.

Prof. Suzanne – Burgoyne, University of Missouri

Suzanne Burgoyne, Ph.D., is a Curators' Distinguished Teaching Professor of Theatre, and Director of MU's Center for Applied Theatre and Drama Research. A Carnegie Scholar, Fulbright, Kellogg National, and Kemper Fellow, she was named Outstanding Teacher 2003 by The Association for Theatre in Higher Education. Since 2013, she has taught Creativity for the Non-Arts Major for MU's honors college. She also has been collaborating with MU bioengineers to teach their capstone students creativity, with promising research results. Suzanne's edited volume, Creativity in Theatre: Theory and Action in Theatre/Drama Education was just published by Springer.

A Creative Approach to the Undergraduate Research Experience

Introduction: *Innovation* and *discovery* are two intended byproducts of engineering research. These byproducts are, however, difficult to achieve, particularly for researchers in training, without the right foundation of knowledge and skills. Because engineering research demands a workforce whose interdisciplinary academic training extends from a sub-atomistic understanding of fundamental science to a broad understanding of complex systems and processes, most research training programs focus on knowledge and skills either specific to the field of research, or on the process of performing research in general, giving students basic competencies in the ability to perform research [1]. However, as the global challenges that our engineering workforce address become increasingly interwoven and complex, it becomes necessary to move beyond these basic competencies during research training programs so that the researchers in training are able to not only understand and apply what they have learned during their training, but also to *innovate* upon it [1-4].

In universities today, research training approaches typically include both formal and informal programs, beginning at the undergraduate level, via research for credit opportunities, research for pay experiences, research bootcamps, and more intensive summer programs, like the National Science Foundation's (NSF's) Research Experiences for Undergraduates (REU) program. These programs frequently rely on traditional master/apprentice relationships, where students learn about the research process and gain skills in the specific field of research directly under the guidance of a more experienced researcher. In the last two decades, this model has been improved upon dramatically [5-9], leading to many university-wide programs designed to help any student wishing for research experience to gain a broad understanding of the research process and how to perform specific tasks within that process without needing a one-on-one approach to guidance. These programs include seminars, workshops, and in-classroom learning experiences focused on research skills that underlie all fields, such as performing literature searches, using citation software, communicating scientific results through written and oral formats, participating in mandatory safety trainings, learning how to establish an appropriate social media presence, practicing building professional networks, and learning additional "professional skills" that help students develop personally and professionally. The result of these efforts can be exceptionally well-trained, well-rounded undergraduate researchers who are ready to tackle their first research project with confidence and able to pursue higher-level research training opportunities that provide a deep-dive into a specific field of research or complex problem [5, 6, 8].

However, these training programs do not provide a specific approach for training researchers how to *innovate;* rather, they operate on the assumption that a well-prepared researcher will naturally be able to innovate simply by performing routine research tasks. Unfortunately, this approach, whether in research training programs or traditional academic programs, has not led to a workforce capable of innovating at the level required for rapid research progress. For instance, when employers across industries were asked the level of preparedness for creative and innovative thinking in recent hires, 25% of employers believed students lacked preparation in these areas [10]. Indeed, employers continue to demand more creative thinking in recent graduates, particularly engineering graduates, than they are currently demonstrating [11-13]. This is particularly startling given that the continuous growth rate of engineering careers, as determined by a study from the U.S. Bureau of Labor Statistics [14], is in part due to the innovations and ideas generated by engineers. These innovations maintain social prosperity by addressing urgent social and global problems, such as new ways to produce energy to address energy shortages [3, 15]. As innovation has become a necessity for societal progress to occur, so, too, is innovation a necessary component of the U.S. economy; driving innovation therefore drives the economy [2, 16-18].

This problem arises, in part, because we do not systematically teach the foundations of innovation, creativity, and creative thinking, in our engineering curricula or typical research training programs [12, 19-21]. Indeed, many students maintain that creativity is either something you have or something you do not have; that is, creativity is an innate skill that cannot be learned. Although many view creativity as a fixed character trait, researchers have demonstrated that all humans are born with the innate capability for creativity; however, this ability is diminished if not nurtured and practiced.[22] Because creativity is not emphasized in school or other training programs, many students lose their creative abilities and thereafter believe they are not creative. Recently, researchers, teachers, and neuroscientists have developed methods to reawaken human creativity and eliminate psychological blocks that restrict divergent thinking and hinder innovation [4, 7-9, 19, 20, 23-25]. The results of these studies show that innate creative thinking and expression, if properly fostered, could help develop students, and particularly, engineers, into 21st century innovators [26].

However, even though many instructors and research mentors have good intentions towards including creativity in their instruction/training process [4, 27], studies demonstrate that engineering students' level of creativity actually *decreases* over the course of their training [6, 8, 28]. Creativity or creative thinking has been largely absent or unsupported in the standard engineering curriculum, let alone research training programs, due to a number of factors, including faculty's lack of knowledge of how to properly teach creativity and creative thinking and how to integrate such teaching into the existing curriculum [5, 28-31]. Thus, the field of engineering is tasked with maintaining its innovativeness by promoting and nurturing creativity within the profession, without having the appropriate tools to do so [19-21]. Despite these unfortunate circumstances, recent studies have demonstrated that when creativity *is* methodologically inserted in the engineering curriculum or other skill-based training programs, students are able to apply it immediately and in the long-term.[9] For instance, within the corporate world, the idea of creativity training has gained recent significant attention due to its ability to enhance worker performance in organizations [32] and impact economic development in cities [33, 34]. For example, the integration of creativity-based approaches into systematic processes resulted in the optimization of product development [35, 36]. Similarly, in our work, we have found that senior engineering students' engineering design self-efficacy was substantially increased through particular creativity training [37]; other benefits associated with teaching creativity in the engineering curriculum derive from the overall increase in student performance [7, 38]. During this work, our group measured substantial increases in key outcome measures of creativity from engineering students who underwent a semester-long senior design course using evidence-based methods (that implement specific creativity learning methods into the traditional engineering coursework) [39-42].

None of these studies, however, has focused on the impact of creativity training within a *research* training program. This seems odd, considering that, by its very nature, successful, cutting-edge research requires innovation and therefore creative thinking. While many factors and experiences, such as those listed above, go into developing the engineering undergraduate students of today into the successful engineering researchers of tomorrow, the critical factor that these experiences should seek to promote is students' ability to innovate. **This requires students to think not only critically, but more importantly, to think creatively.**

With this knowledge, we intended to extend our work on incorporating evidence-based creativity training in the engineering curriculum to include undergraduate students involved in formal research training programs. We developed the guiding research questions for this paper, which include: 1) Will our method of integrating creativity into a traditional classroom, also show similar improvements in outcome measures when used to integrate creativity into a formal undergraduate research training program? 2) Can we facilitate undergraduate researchers to become more creative when performing their research? In this paper, we discuss the results of our methods on students' creative processes following an 8-week summer undergraduate research program.

Methods: In order to understand our approach to integrating creativity into a formal research training program, we must first have an understanding of what we mean when we state the term "creativity." Creativity may be defined by the results of the creative activity itself; that is, creativity results in the production of something that is (1) original and 2) recognized as useful [43]. Additionally, researchers often view creativity in terms of the "*four P* framework": *Product, Person, Process, and Press* (environment) [44]. In this framework, our approach to creativity training focuses on *process,* that is "the processes involved during creative work or creative thought." [25] Alternatively, Csikszentmilalyi divided creativity into 'Big C' and 'little c' regimes, where "Big C" creators produce major ideas that change their discipline, while "little c" creators come up with ideas that make everyday life better[45]. Finding the 2-C model too limited, Beghetto and Kaufman [46] added 2 additional c's: 1) pro-c level creativity, demonstrated by professionals who haven't reached Big-C eminence and 2) mini-c creativity, which focuses on personally meaningful discoveries that may occur while a student is learning. All of these definitions reflect the idea that creativity is the foundation of innovation; as innovation is recognized as something new (product, process, *etc*.). Furthermore, creativity generates spaces where meaningful ideas impact society.

To implement this approach, we relied on an evidence-based, active learning process that integrates techniques drawn from actor training, improvisation, and theatre of the oppressed[47] with creative problem-solving methods drawn from multiple, research-based sources [22], and tailored specifically to the needs of engineering undergraduate students undergoing formal research training. The combination of techniques was chosen on the understanding from the literature that in order to be creative, students must be willing to risk trying something new and be willing to make mistakes.[48] Theatre exercises enable students to open their minds, question assumptions, and see things differently; moreover, they help lower the stakes for students who may be uncomfortable with a process that may be completely foreign to them. These activities have been shown to improve students' abilities to think creatively in a typical classroom environment [22, 49].

In the summer of 2018, our group sought to implement similar, evidence-based creativity activities into our National Science Foundation (NSF) Research Experience for Undergraduate (REU) Site's programming, intending to train the REU students to become creative thinkers and innovators in all aspects of their professional lives. Following IRB approval (IRB# 2011581), a cohort of students (N=12) was recruited from a pool of students participating in summer undergraduate research program at the University of Missouri, including students sponsored by our NSF REU Site (NSF Award #1757936). Students received one hour per week of creativity training developed by theatre professor Dr. Suzanne Burgoyne (Director of the Center of Applied Theatre and Drama Research), and implemented by Drs. Heather Hunt and Ferris Pfeiffer. The latter have three years of experience working with Burgoyne's creativity training program, developed for undergraduate Honors students and tailored to engineering students specifically [40-42]. Students worked with a research project mentor over the 9-week REU experience, as well as attended weekly creativity instruction studio sessions adapted from our classroom-based work in our bioengineering senior design courses [39-42]. The goals of the studio sessions were not only to train students to think creatively, but also to allow them to practice what they learned in the context of their developing research projects. The week-by-week description of studio activities includes:

<u>Week 1: Enabling Creativity by Developing a Safe Environment</u> - Provide background information about creativity using TED talk video of Sir Ken Robinson "Do Schools Kill Creativity?" Develop and discuss ground rules that will assure a safe environment for free and open exchange of ideas.
<u>Week 2: Active Listening in Research Innovation</u> - Read Sawyer's *Zig-Zag[22]*, Introduction and Chapter 1, to provide background information on the need for active listening. Facilitate "What I heard you say…" activity to illustrate the process of active listening.
<u>Week 3: Understanding and Challenging Assumptions</u> - Introduce and facilitate the "What if…" game to identify and challenge traditional assumptions in various case studies.
<u>Week 4: Convergent and Divergent Thinking in Research, Innovation, and Entrepreneurship</u> - Utilize "What is the best way to squeeze toothpaste from a tube?" discussion/activity to introduce the idea of convergent and divergent thinking. Show the TEDx Talk "The Shape of Creativity" to further discuss the idea and why it is important in the design process. Ask students to identify the convergent solution to their research problem, and to provide at least three divergent thinking alternatives based on discussions.
<u>Week 5: Reframing the Question</u> – Present case studies to facilitate discussions of research questions as provided by users and reframed following further exploration. Students rewrite their research question to include a consideration of the overall goal of the research rather than simply as initially presented.
<u>Week 6: Generating Solutions</u> – Engage students with case studies that illustrate the process of generating solutions to problems. Students will generate at least three possible solutions to their research question.
<u>Week 7: Evaluating Solutions</u> – Engage students with case studies that illustrate the process of evaluating solutions to problems. Students will evaluate their solutions in the context of design requirements previously defined for the problem.
<u>Week 8: Communicating a Solution</u> - Students will be shown various communication methods from technical to informal. Students will be asked to prepare and present a short "pitch" of their solution to an audience of individuals representing various interest groups.

Students were assessed pre- and post-semester using a version of Guilford's test [50, 51] to evaluate baseline as well as changes in creative thinking. Additionally, students were evaluated using the Torrance Test for Creative Thinking (TTCT) [52] such that their current level of creative thinking could be compared to national averages using a validated outcome measure. The TTCT is a highly reliable creative thinking measure that has been used to identify creatively gifted children through adults in the U.S., especially in multicultural settings. The tests invited students to write questions, reasons, and different uses for objects, as well as consequences for their use. The results were assessed for fluency, flexibility, and originality, and can be scored locally using the Manual for Scoring and Interpreting Results that comes with the assessment. Similarly, Guilford's test asked students to list as many possible uses for a common household item (like a brick) that they can identify. Scoring for Guilford's test used the same four components: fluency, flexibility, originality, and elaboration; the assessment was repeated following the semester and scoring followed a simple rubric. Fluency is a measure of the number of solutions to a problem produced during the evaluation (for example a student may find 15 uses for a brick). Flexibility is a measure of the variety of a student's solutions. If all solutions use the brick as a building material that shows low flexibility, while using the brick to produce a painting as well as grind food shows higher flexibility. Originality is a measure of how different a student's solutions are from the norm. Students would not receive credit for uses that involve using the brick as a building material as that is the normal use for a brick. Finally, elaboration is a measure of the level of detail provided in each solution. Scoring was done using a predefined rubric by a blinded evaluator.

Results: REU students were evaluated for change in creative thinking across the training program (Summer Semester) with pre- and post-semester assessments using a version of Guilford's test. The pre/post semester evaluation included 4 measures of creativity: 1) fluency (the total number of solutions provided), 2) flexibility (the variety of solutions provided), 3) originality (difference in solutions from the norm), and 4) elaboration (the level of detail given in each solution). Aggregate pre- and post-semester values are included in figure 1.

Individual student pre- and post- semester values are included in figures 2-5 below. It should be noted in figures 2-5 that all twelve students completed the pre-semester assessment, but only nine students completed the post-semester assessment. Three students completed the instruction but were not present during the final assessment day due to other obligations. The aggregate values in figure 1 only include the nine students for which we have a complete data set. Individual student pre-semester scores are included for all twelve students simply for completeness.

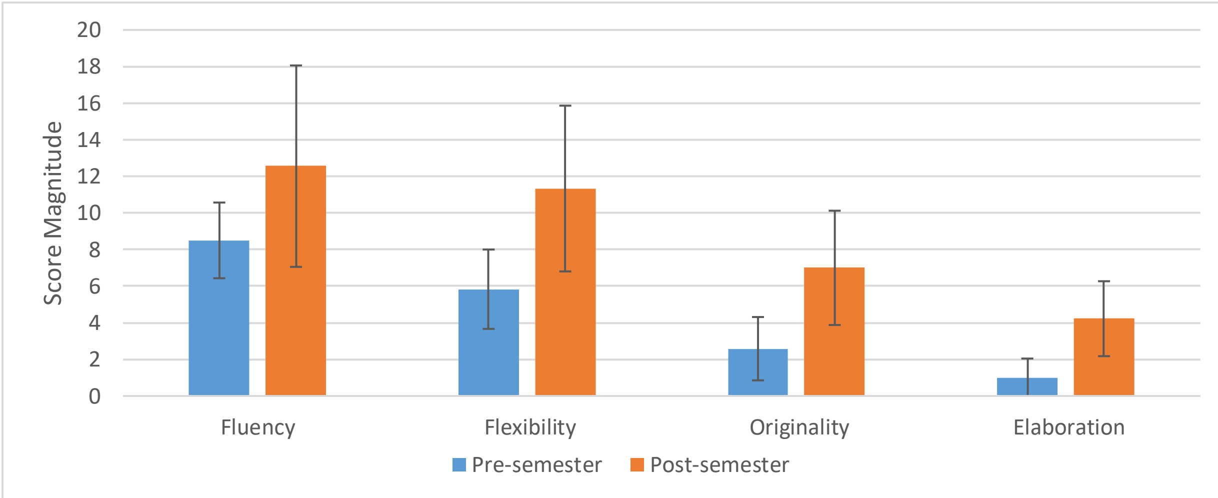

Figure 1. Pre- and post-semester measure of aggregate REU student creativity outcome measures show that post-intervention, the students scored higher on all four measures of Guilford's test.

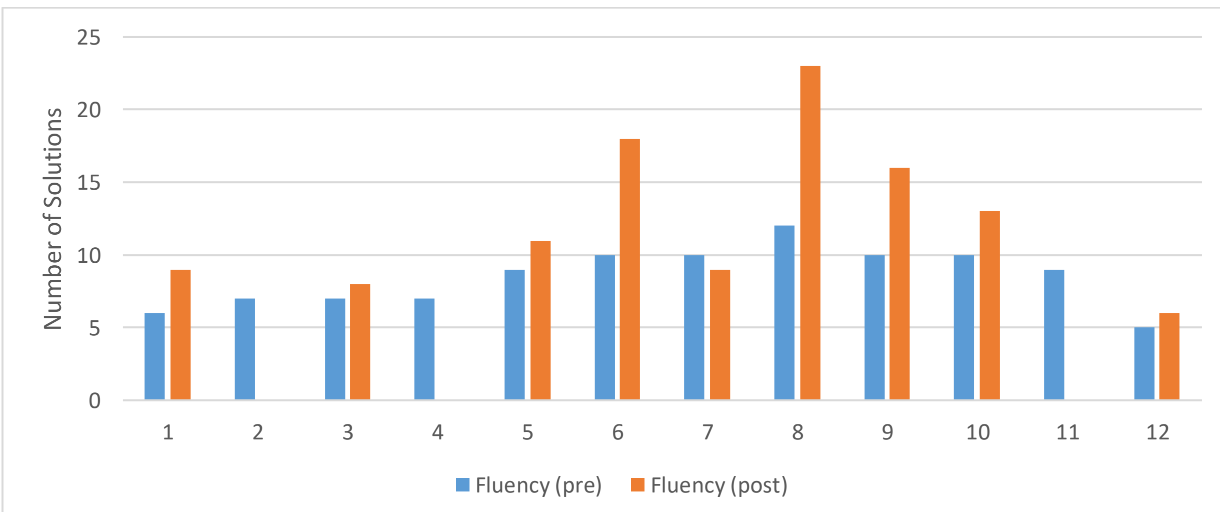

Figure 2. Pre- and post-semester measure of REU student creative fluency (number of solutions), by student, shows that all but one student had greater fluency after the intervention. Note that three students did not take the post-assessment due to travel arrangements.

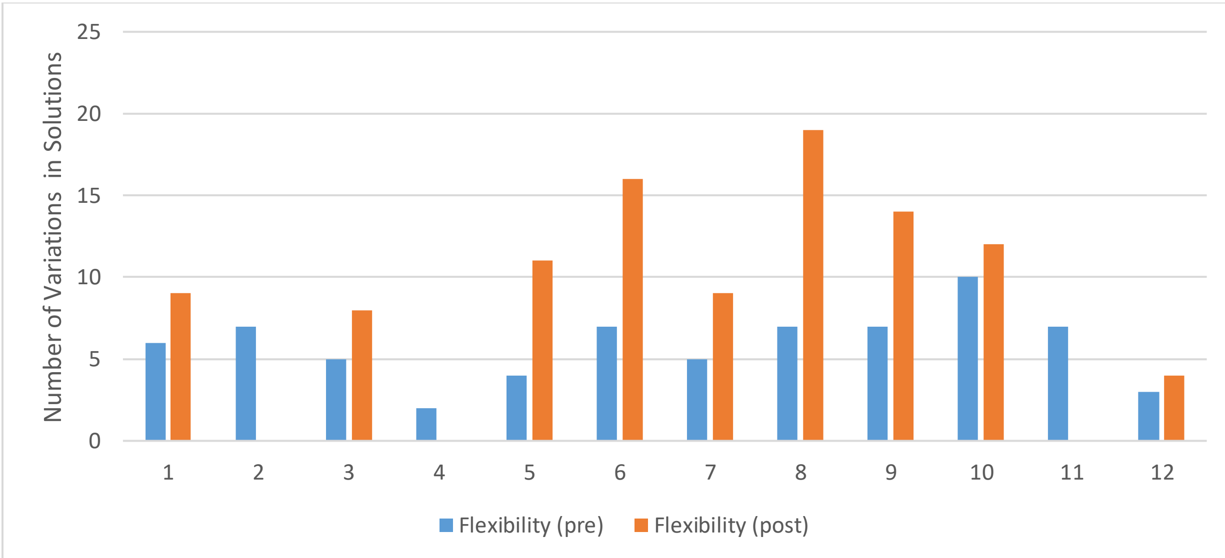

Figure 3. Pre- and post-semester measure of REU student creative flexibility (variations in solutions), by students, shows that all students demonstrated greater flexibility in their solutions after the intervention. Note that three students did not take the post-assessment due to travel arrangements.

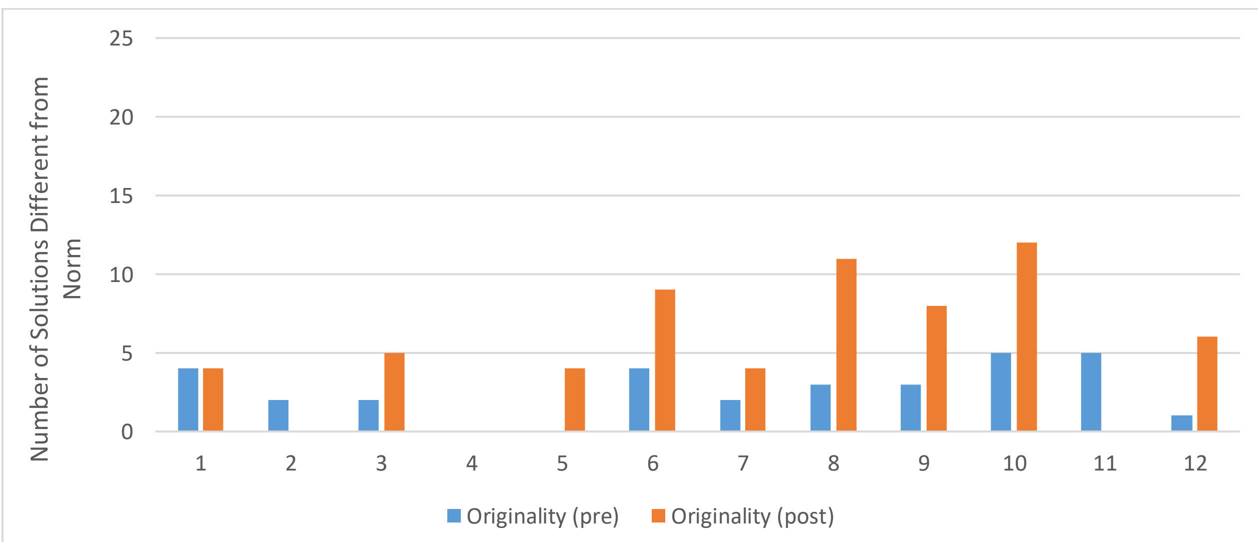

Figure 4. Pre- and post-semester measure of REU student creative originality (difference from the norm in solutions) show that, after the intervention, all students showed greater originality in the solutions that they described than before the intervention. Note that three students did not take the post-assessment due to travel arrangements.

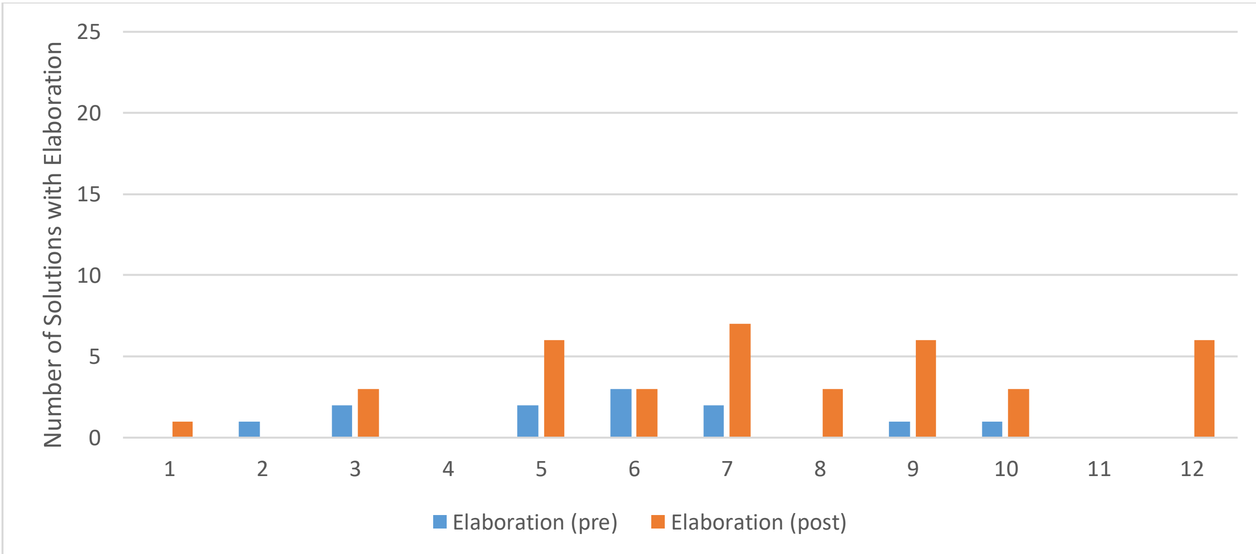

Figure 5. Pre- and post-semester measure of REU student creative elaboration (level of detail provided in solutions) demonstrates that all the students for whom we had both pre- and post-data had more detail provided in their solutions after the intervention. Note that three students did not take the post-assessment due to travel arrangements.

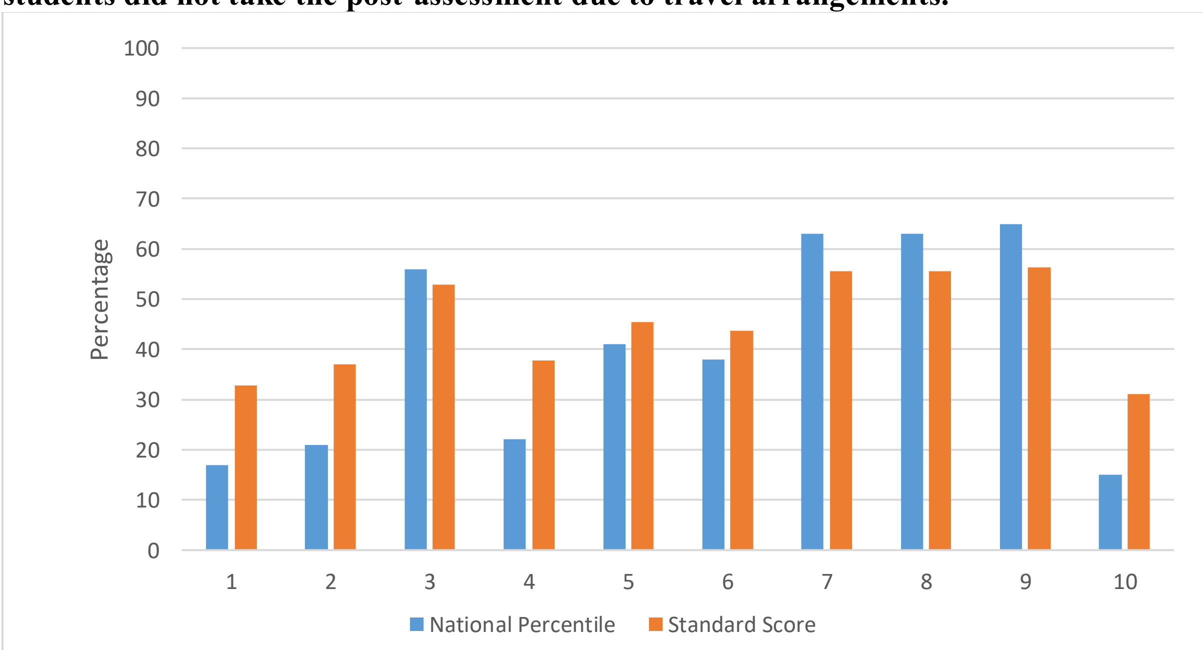

Figure 6. Standard Score and National Percentile for REU students surveyed as measured using the Torrance Test for Creative Thinking.

Additionally, REU students (n=10) were evaluated for creative thinking ability at the completion of the 8 week semester using the Torrance Test for Creative Thinking (TTCT) as well as the version of the Guilford test mentioned previously. The results from the TTCT, including standard scores (on a scale from 41-160 converted to a percentage between 0 and 100), as well as the national percentile (on a scale from 0 to 100), are shown in figure 6.

Discussion: According to the results of the Guilford-based test, students who participated in the 8-week creativity training demonstrated a substantial increase in their creative thinking abilities (figures 1-5). In fact, we observed a **44% increase in fluency** (8.5 pre vs 12.5 post, figure 3), a **91% increase in flexibility** (5.8 pre vs 11.3 post, figure 4), a **168% increase in originality** (2.6 pre vs 7.0 post, figure 5), and a **300% increase in elaboration** (1.0 pre vs 4.2 post, figure 6). This data indicates that high achieving engineering students (such as those selected for this NSF REU Site) have a substantial ability to increase their demonstrated creativity using validated outcome measures following a short-duration, targeted intervention. Due to the relatively low number of students in this study, we did not believe it feasible to attempt to calculate statistical differences or attempt to draw any statistical conclusions at this time, even though the results indicated a positive response. We will be continuing this work over the remaining summers of the NSF-funded award, and we hope to increase our sample size by continuing to include other students performing research who are not participants in our NSF REU Site. This should enable us to gain a statistical understanding of the impact of our methodology.

Interestingly, however, the results from the Torrance Test for Creative Thinking, administered at the end of the summer, indicated that the engineering students in this NSF REU Site cohort exhibited a level of creative thinking that was *below* the national average for students from all disciplines (not just engineering) of the same age (figure 6). The mean standard score for the group was 93.3 with a standard deviation of 11.7. This is based on a scale from 41-160 with a score of 100 being the 50^{th} percentile. There were four students in this cohort that scored above 100 with the high score of 107. Six students scored below 100 with a low score of 77. Comparing these data to the national profile, the mean of the national percentile ranking for the cohort was 40.1% with a standard deviation of 20.5. This is based on a scale from 0% to 100%. Using this scale, four of our student participants ranked above the 50^{th} percentile, with a high percentile of 65%. Six students ranked below the 50^{th} percentile, with the lowest being 15%. Although this is a small sample size, our data indicates that ***even high-achieving engineering students*** (such as those recruited for this NSF REU Site) ***did not demonstrate creativity at or above the national average***. This is particularly concerning, as our society relies heavily on engineers for discovery and innovation now and in the future. We note that the TTCT and the Guilford-based instrument measure different aspects of creativity; indeed, creativity is a complex construct, and no one measure is likely to fully capture it.

Conclusion: In this work, we attempted to answer two guiding questions: 1) Will our method of integrating creativity into a traditional classroom, also show similar improvements in outcome measures when used to integrate creativity into a formal undergraduate research training program?2) Can we facilitate undergraduate researchers to be more creative when performing their research? **The results from this study indicate that our method of integrating creativity showed substantial improvements in the measure of creativity exhibited by students who participated in the undergraduate research training program.** Therefore, the answer to our first research question is "yes" our method showed similar improvements in outcome measures for student creativity. The answer to the second research question is less definite. We did observe more creativity in the student research projects. However, we did not have a sufficient outcome measure to determine the magnitude or cause of such observations. He hypothesize that the increased creativity exhibited by and measured in the students was a significant contributing factor to the observations of creativity in their research. More study is needed to test this hypothesis.

Although the substantial increases we saw using the Guilford-based instrument are encouraging, we still have room for improvement in teaching engineers and engineering researchers-in-training to think creatively. Additionally, this study has brought to light unanswered questions. Specifically, will the results we found be maintained as these students continue along their educational and career paths? Also, can these interventions be woven into traditional engineering courses and yield similar results? The results of this work indicate that the benefits of such an intervention are well worth the efforts to explore these and other related questions as the discovery and innovation potential of current and future engineers is directly related to their abilities to think creatively as they problem solve.

While this is the first step in a longer study, engineering educators and directors of research training programs will be able to use these results and our methodology as a foundation for improving the ability of their students to innovate, both in the classroom and in their research programs. The approach presented here can be easily translated across campus and across research disciplines to broadly impact a wider array of undergraduate researchers in training. This paper presents, for the first time, a straightforward, evidence-based approach to improving undergraduate researchers-in-training's creativity and creative thinking skills. When we deliberately incorporate this type of creativity training into existing, formal research training programs, we pave the road for the next generation of engineering researchers to *discover* and to *innovate*.

REFERENCES

[1] N. A. o. E. 2005, *Engineering Research and America's Future: Meeting the Challehges of a Global Economy*. Washington, DC: The National Academies Press, 2005.

[2] J. Estrin, *Closing the innovation gap : reigniting the spark of creativity in a global economy / Judy Estrin.* New York, NY: McGraw-Hill, 2009, p. 254.

[3] N. S. Foundation, "Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital," *National Science Foundation,* p. 62, 2010.

[4] T. Haertel, C. Terkowsky, and I. Jahnke, "Where have all the inventors gone?," *Proceedings of ICL,* pp. --, 2012.

[5] A. A. Astin, Helen S., "Undergraduate Science Education: The Impact of Different College Environments on the Educational Pipeline in the Sciences. Final Report.," UCLA, Los Angeles, CA1992, Available: https://files.eric.ed.gov/fulltext/ED362404.pdf.

[6] N. Genco, Hölttä-Otto, K. and Seepersad, C. C. , "An Experimental Investigation of the Innovation Capabilities of Undergraduate Engineering Students," *Journal of Engineering Education,* vol. 101, pp. 60-81, 2012.

[7] A. Perez-Poch, Olmedo-Torre, N., Sánchez, F., Salán, N. López, D., "On the Influence of creativity in basic programming learning in a first-year engineering course " *International Journal of Engineering Education,* vol. 32, pp. 2302-2309, 2016.

[8] E. Sola, R. Hoekstra, S. Fiore, and P. Mccauley, "An investigation of the state of creativity and critical thinking in engineering undergraduates," *8,* pp. 1495-1522, 2017.

[9] A. Valentine, I. Belski, and M. Hamilton, "Engaging engineering students in creative problem solving tasks: How does it influence future performance?," in *44th SEFI*

Conference: Engineering Education on Top of the World: Industry University Cooperation, 2016, pp. 1-9: European Society for Engineering Education.
[10] H. R. Associates, "Falling Short? College Learning and Career Success," (in English), *NACTA Journal,* vol. 60, no. 1a, pp. 1-6, 2016.
[11] A. Blom and H. Saeki, "Employability and skill sets of newly graduated engineers in India: a study," *IUP Journal of Soft Skills,* vol. 6, no. 4, p. 7, 2012.
[12] P. Tulsi and M. Poonia, "Expectations of industry from technical graduates: Implications for curriculum and instructional processes," *Journal of Engineering Education Transformations,* pp. 19-24, 2015.
[13] A. Zaharim, Y. Yusoff, M. Z. Omar, and A. Mohamed, "Perceptions and expectation toward engineering graduates by employers : a Malaysian study case," *WSEAS TRANSACTION on Advances in Engineering Education,* vol. 6, pp. 296-305, 2009.
[14] U. S. D. o. L. Bureau of Labor Statistics. (2016). *The Economics Daily, Employment outlook for engineering occupations to 2024*. Available: https://www.bls.gov/opub/ted/2016/employment-outlook-for-engineering-occupations-to-2024.htm
[15] M. M. Clapham, "The development of innovative ideas through creativity training," in *International Handbook on Innovation*Oxford: Elsevier, 2003, pp. 366–376.
[16] D. Ryan, H. John, J. Ron, and M. Javier, "The Role of Entrepreneurship in US Job Creation and Economic Dynamism," *The Journal of Economic Perspectives,* research-article no. 3, p. 3, 2014.
[17] J. J. Kao, *Innovation nation : how America is losing its innovation edge, why it matters, and what we can do to get it back* New York, NY: Free Press, 2007, p. 306.
[18] A. Hausman and W. J. Johnston, "The role of innovation in driving the economy: Lessons from the global financial crisis," *Journal of Business Research,* vol. 67, no. 1, pp. 2720-2726, 2014/01/01/ 2014.
[19] D. H. Cropley, "Creativity in engineering education," pp. 155-173, 2015.
[20] D. H. Cropley, "Promoting creativity and innovation in engineering education," *Psychology of Aesthetics, Creativity, and the Arts,* vol. 9, no. 2, pp. 161-171, 2015.
[21] D. H. Cropley, *Teaching Engineers to Think Creatively: Barriers and Obstacles in STEM Disciplines*. London: routledge, 2015.
[22] K. Sawyer, *Zig-Zag: The Surprising Path to Greater Creativity*. San Francisco: Jossey-Bass, 2013.
[23] D. H. Cropley, *Teaching Engineers to Think Creatively: Barriers and Obstacles in STEM Disciplines* (The Routledge International Handbook of Research on Teaching Thinking). London: Routledge, 2015.
[24] R. Beghetto, *Killing Ideas Softly? The Promise and Perils of Creativity in the Classroom*. Information Age Publishing, Inc, 2013.
[25] K. Sawyer, *Explaining Creativity: The Science of Human Innovation*, 2nd ed. New York: Oxford University Press, 2012.
[26] S. Zenios, J. Makower, P. Yock, T. Brinton, U. Kumar, L. Denend, and T. Krummel, *Biodesign: The Process of Innovating Medical Technologies*. New York: Cambridge University Press, 2010.
[27] G.-A. Amoussou, M. Porter, and S. J. Steinberg, "Assessing creativity practices in design," in *Frontiers in Education Conference (FIE), 2011*, 2011, pp. S2B-1-S2B-6: IEEE.

[28] K. Kazerounian and S. Foley, "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions," *Journal of Mechanical Design,* vol. 129, p. 761, 2007.
[29] P. A. Daempfle, "An Analysis of the High Attrition Rates among First Year College Science, Math, and Engineering Majors," *Journal of College Student Retention: Research, Theory & Practice,* vol. 5, no. 1, pp. 37-52, 2003.
[30] R. M. Marra, K. A. Rodgers, D. Shen, and B. Bogue, "Leaving Engineering: A Multi-Year Single Institution Study," *Journal of Engineering Education,* vol. 101, no. 1, pp. 6-27, 2012.
[31] L. J. Shuman, C. Delaney, H. Wolfe, A. Scalise, and M. Besterfield-Sacre, "Engineering attrition: Student characteristics and educational initiatives," in *Proceedings of the American Society of Engineering Education*, 1999, pp. 1-12.
[32] A. Somech and A. Drach-Zahavy, "Translating team creativity to innovation implementation: The role of team composition and climate for innovation," *Journal of Management,* vol. 39, no. 3, pp. 684-708, 2013.
[33] R. A. Boschma and M. Fritsch, "Creative class and regional growth: Empirical evidence from seven European countries.," *Economic geography,,* vol. 85, no. 4, pp. 391-423, 2009.
[34] E. Marrocu and R. Paci, "Education or Just Creativity: What Matters Most for Economic Performance?," *SSRN Electronic Journal,* 2011.
[35] A. Brattström, H. Löfsten, and A. Richtnér, "Creativity, trust and systematic processes in product development," *Research Policy,* vol. 41, no. 4, pp. 743-755, 2012.
[36] L. L. Gilson, J. E. Mathieu, C. E. Shalley, and T. M. Ruddy, "Creativity and standardization: complementary or conflicting drivers of team effectiveness?," *Academy of Management journal,* vol. 48, no. 3, pp. 521-531, 2005.
[37] F. M. Pfeiffer, R. E. Bauer, S. Borgelt, S. Burgoyne, S. Grant, H. K. Hunt, J. J. Pardoe, and D. C. Schmidt, "When theater comes to engineering design : Oh how creative they can be," *Journal of Biomechanical Engineerng,* vol. 139, no. 7, pp. 1-4, 2017.
[38] W. Carpenter, "Engineering Creativity : Toward an Understanding of the Relationship between Perceptions of Creativity in Engineering Design and Creative Performance " *International Journal of Engineering Education,* vol. 32, no. 5A, pp. 2016-2024, 2016.
[39] F. M. Pfeiffer, R. E. Bauer, S. Borgelt, S. Burgoyne, S. Grant, H. K. Hunt, J. J. Pardoe, and D. C. Schmidt, "When theater comes to engineering design : Oh how creative they can be," vol. 139, no. 7, pp. 1-4, 2017.
[40] F. M. Pfeiffer, R. E. Bauer, S. Borgelt, S. Burgoyne, H. K. Hunt, J. J. Pardoe, and D. C. Schmidt, "When Theater Comes to Engineering Design: Oh How Creative They Can Be," *Journal of Biomechanical Engineering,* vol. 139, 2017.
[41] F. M. Pfeiffer, S. Burgoyne, H. K. Hunt, J. Strobel, R. E. Bauer, J. J. Pardoe, S. Simkins, L. Vansant, J. Saboorizadeh, K. Busselle, and W. Palmer, *Creativity Theory and Action in Bioengineering Class*, 1st ed. (Creativity in Theatre: Creativity Theory and Action in Drama and Theatre Education). Springer, 2018.
[42] F. M. Pfeiffer, A. Morss-Clyne, and V. Ferguson, "Active Teaching and Learning in Bioengineering," presented at the Summer Biomechanics, Bioengineering and Biotransport, National Harbor, Maryland, 2016.
[43] J. C. Kaufman, *Creativity 101.* . New York: Springer, 2009.

[44] M. Rhodes, "An Analysis of Creativity," *The Phi Delta Kappan,* vol. 42, no. 7, pp. 305-10, 1961.
[45] M. Csikszentmihalyi, *Creativity: Flow and the psychology of invention and innovation*. New York: Harper Perennial, 1996.
[46] R. A. Beghetto and J. C. Kaufman, *Broadening conceptions of creativity in the classroom* (In Nurturing creativity in the classroom, ed.). Cambridge: Cambridge Univ. Press, 2010.
[47] A. Boal, *Games for Actors and Non-Actors*, 2 ed. London: Routledge, 2002.
[48] S. K. Robinson, *Out of Our Minds: Learning to Be Creative*. Chichester: Capstone, 2011.
[49] K. Sawyer, *Group Creativity: Music, Theatre, Collaboration*. Mahwa, New Jersey: Lawrence Erlbaum Associates, 2003.
[50] R. Wilson, J. Guilford, P. Christensen, and D. Lewis, "A Factor-Analytic Study of Creative-Thinking Abilities," *Psychometrika,* vol. 19, no. 4, pp. 297-311, 1954.
[51] M. Wallach and N. Kogan, *Modes of Thinking in Young Children: A Study of the Creativity-Intellegence Distinction*. Praeger, 1965.
[52] E. Torrance, "Predictive Validity of the Torrance Tests of Creative Thinking," *The Journal of Creative Behavior,* vol. 6, no. 4, pp. 236-62, 1972.